Towards a Laser-driven polarized ^{3}He Ion Beam Source

XVI th International Workshop in Polarized Sources, Targets, and Polarimetry (PSTP2015)

Sep 18th, 2015 | Ilhan Engin – IKP-4 *i.engin@fz-juelich.de*

Collaboration

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  Rudolf Maier (emeritus) - IKP-4
  Andreas Lehrach - IKP-4
  Ralf W. Engels - IKP-2

  Paul Gibbon - JSC

  Ilhan Engin - IKP-4

- *GSI Darmstadt:*

  Markus Roth - GSI & TUD
  Oliver Deppert - GSI
  Simon Frydrych - GSI
  Annika Kleinschmidt - GSI

- *FZJ technical support:*

  magnetic holding fields

  Harald Glückler - ZEA-1
  Helmut Soltner - ZEA-1
  Johannes Pfennings - ZEA-1

  general technical support

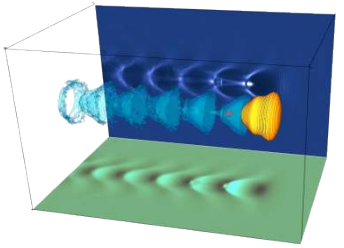
  Knut Dahlhoff - ZEA-1

  pressure booster & piezo valve

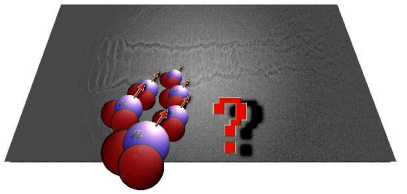
  Herbert Feilbach - PGI-JCNS-TA

Outline

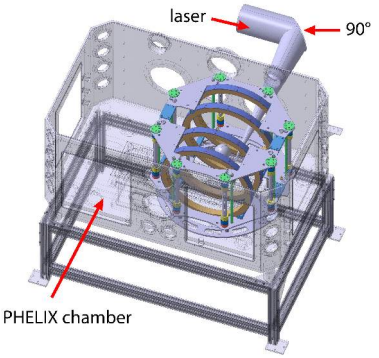
- Lasers as compact accelerators



- Feasibility studies: laser-accelerated ^{3,4}He ions

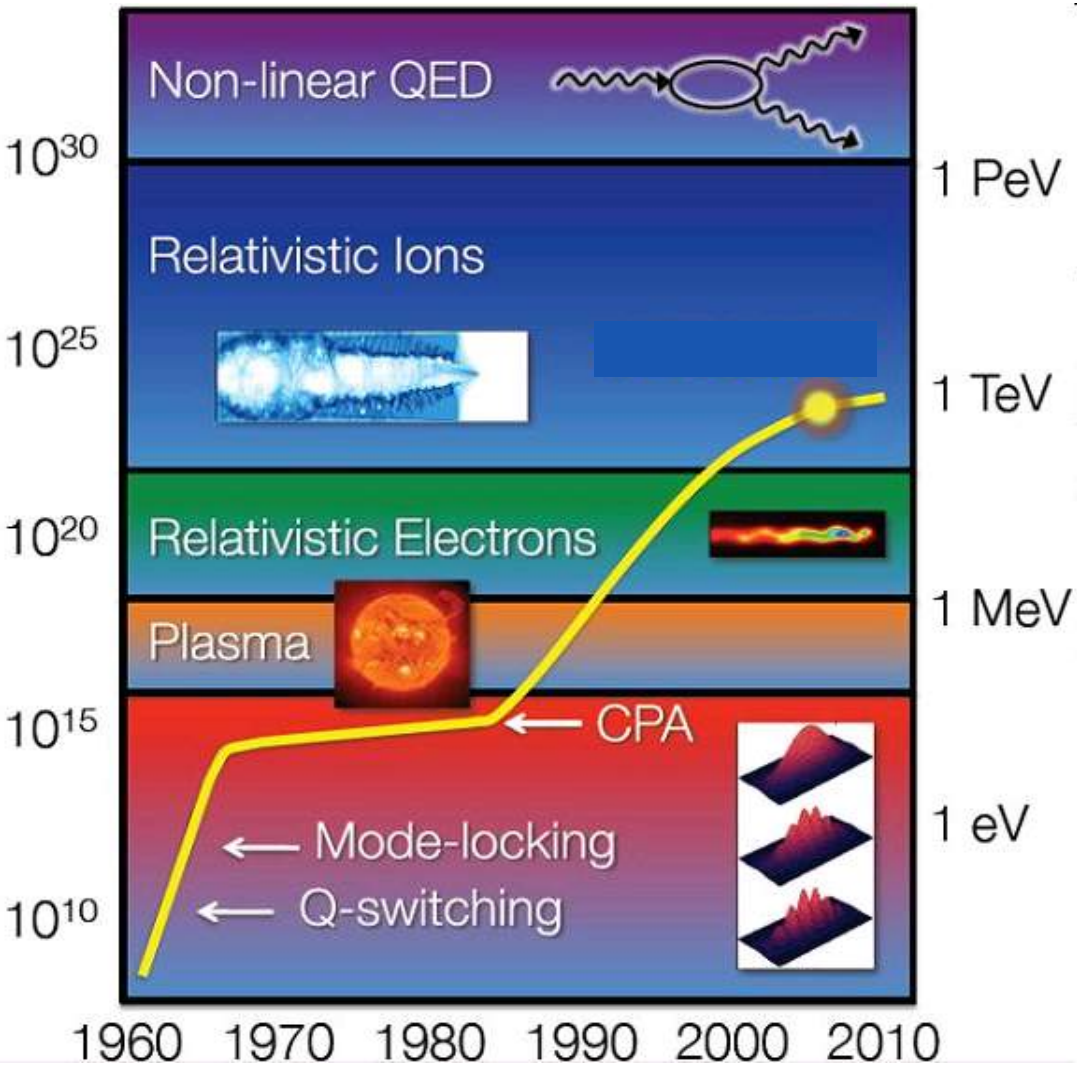


- Polarized ^{3}He target



Development of laser intensities

focused intensity (W/cm^2)



characteristic electron energy

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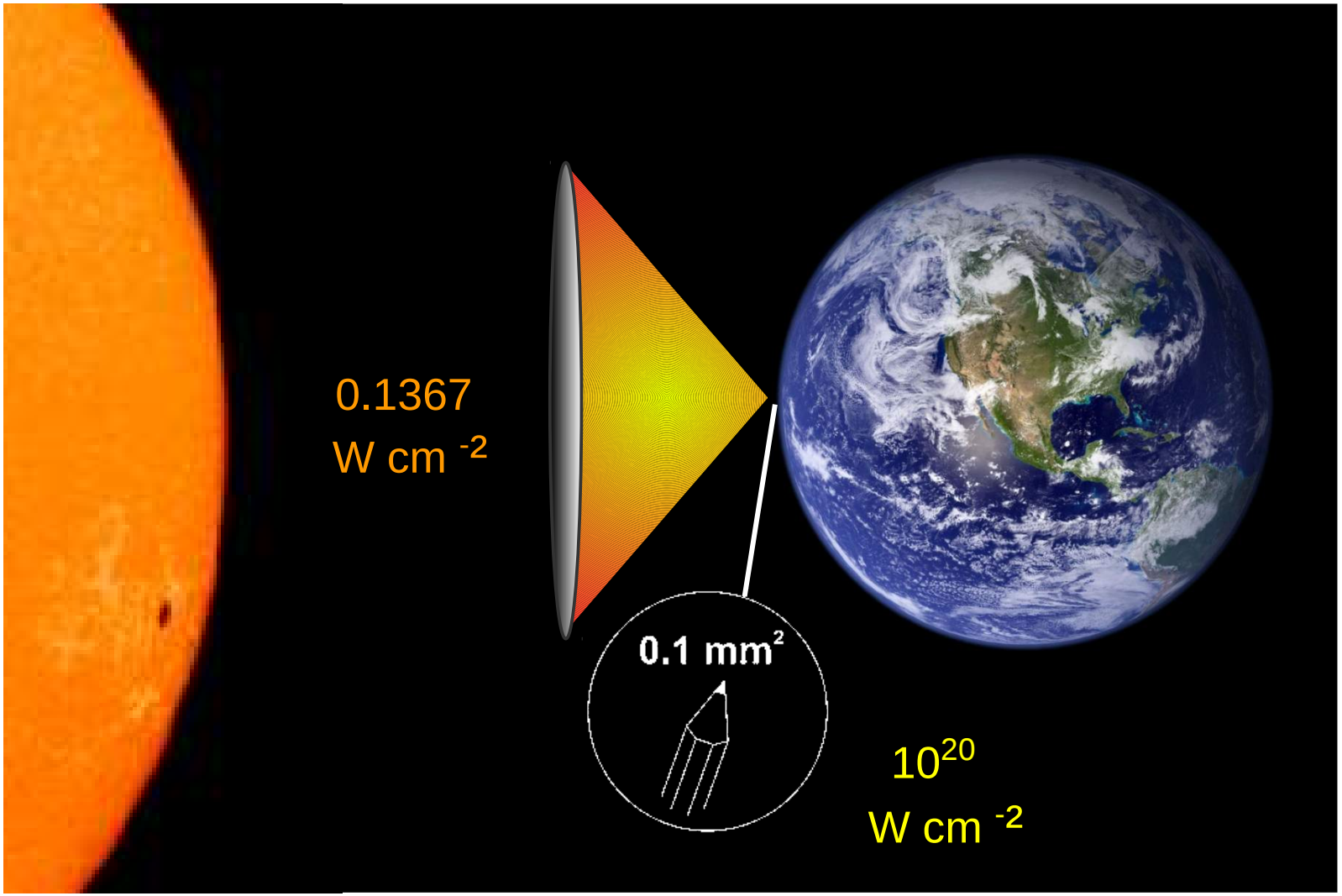
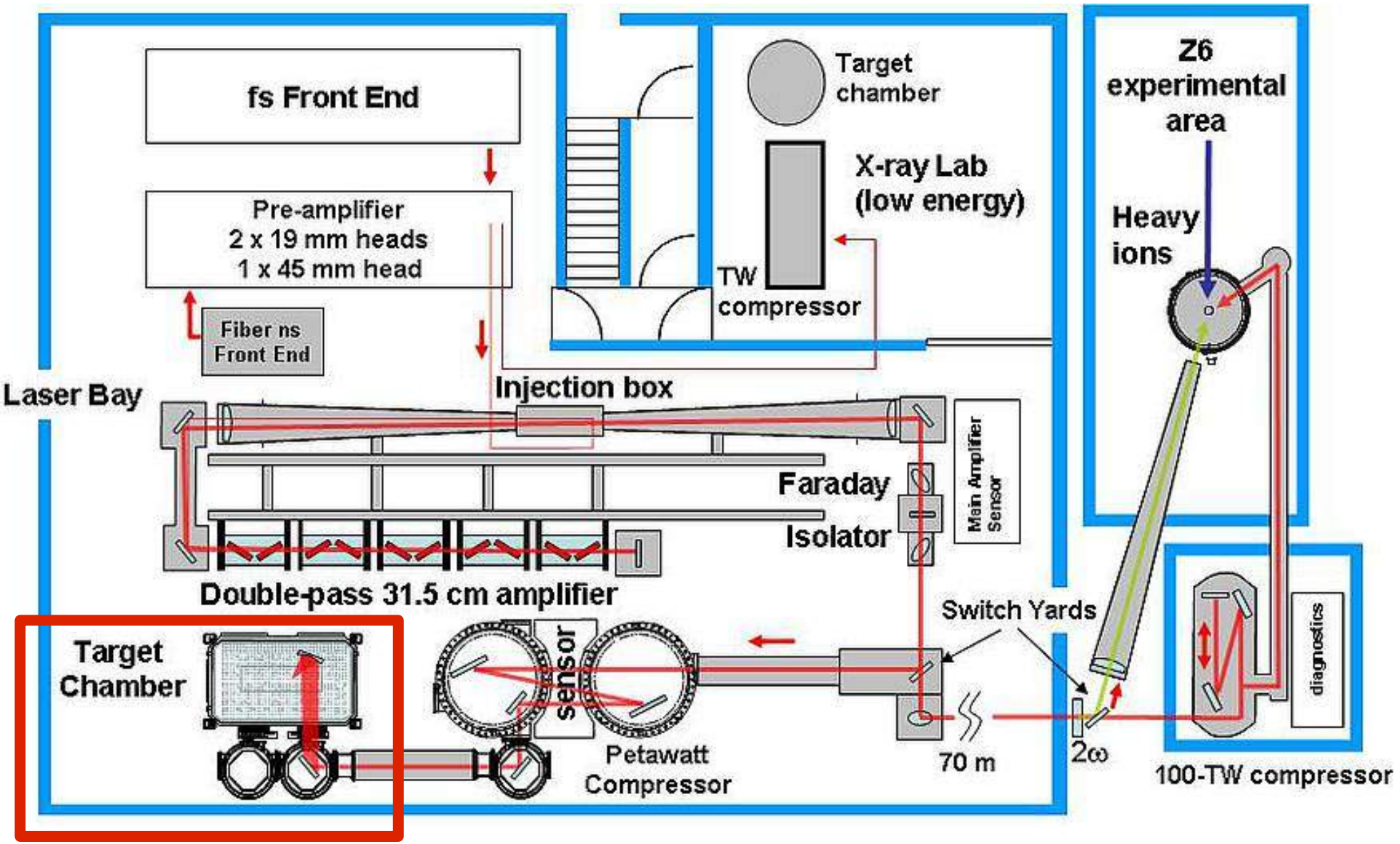
High-intensity lasers



PHELIX @GSI Darmstadt



https://www.gsi.de/fileadmin/_processed_/csm_phelix_overview_e76071901b.jpg

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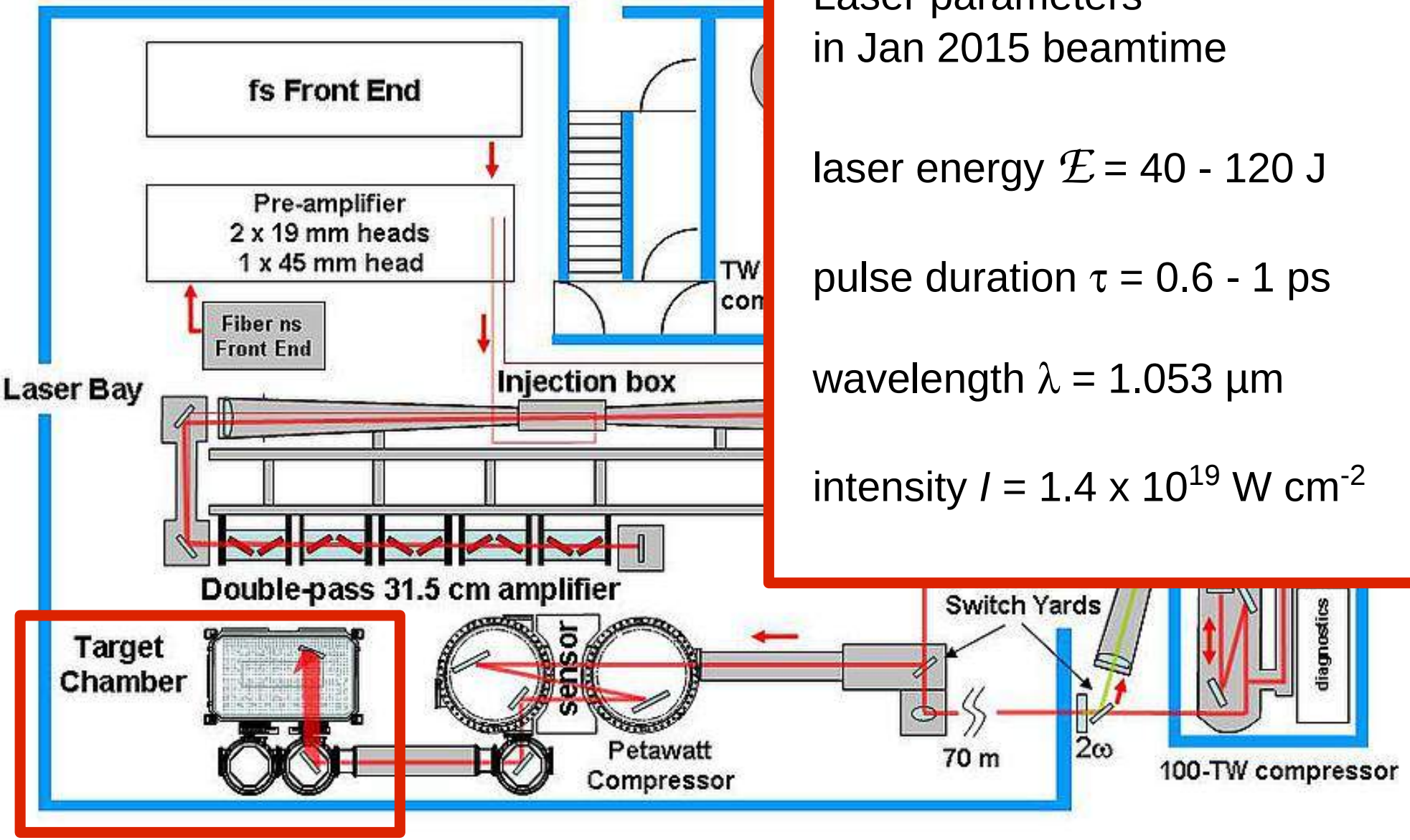


Laser parameters
in Jan 2015 beamtime

laser energy $\mathcal{E}$ = 40 - 120 J

pulse duration τ = 0.6 - 1 ps

wavelength λ = 1.053 µm

intensity I = 1.4 x 10^{19} W cm^{-2}

https://www.gsi.de/fileadmin/_processed_/csm_phelix_overview_e76071901b.jpg

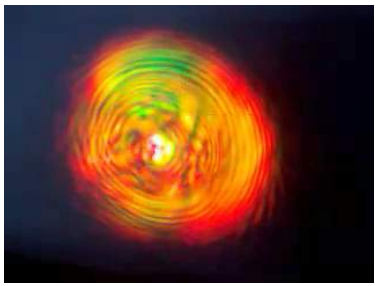
Laser-target interaction

ultra-short
high-intensity
laser pulse

$I \sim 10^{19\text{-}20}$ W cm $^{-2}$

target

gas jets
underdense **plasma**



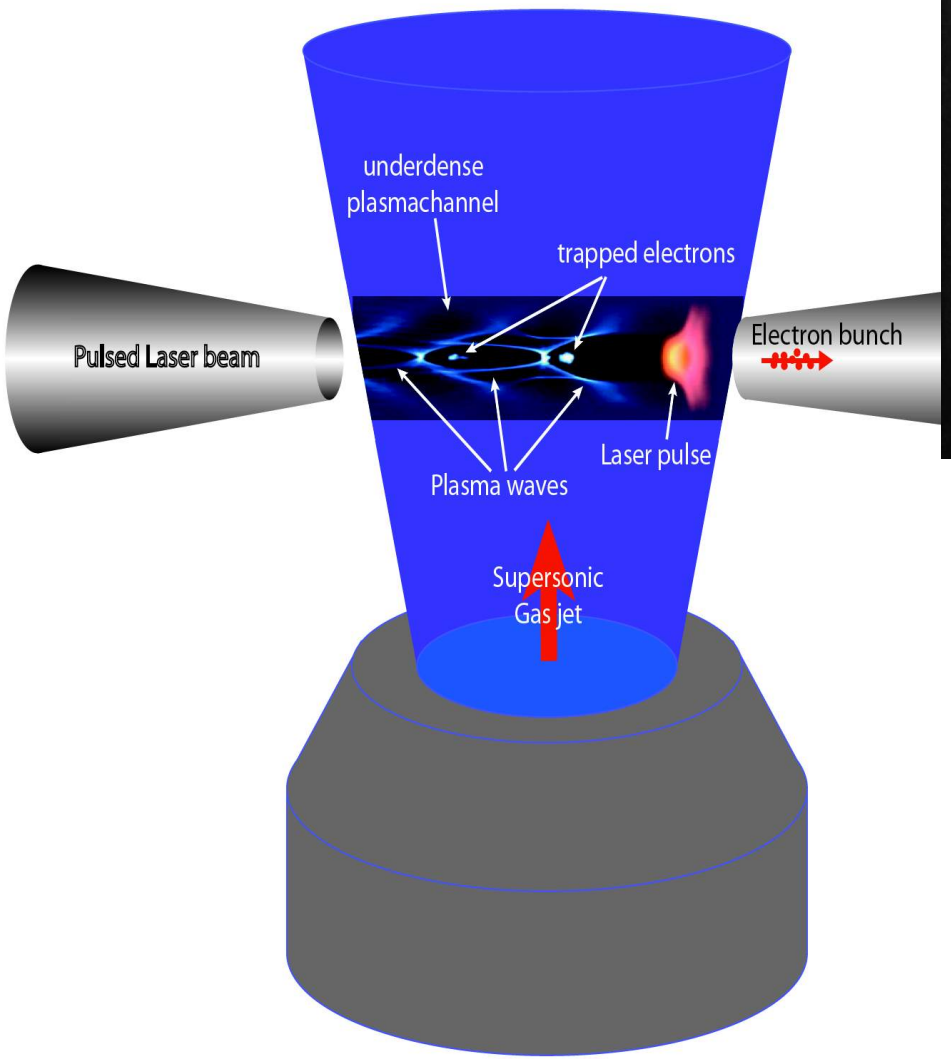
solid targets
overdense **plasma**

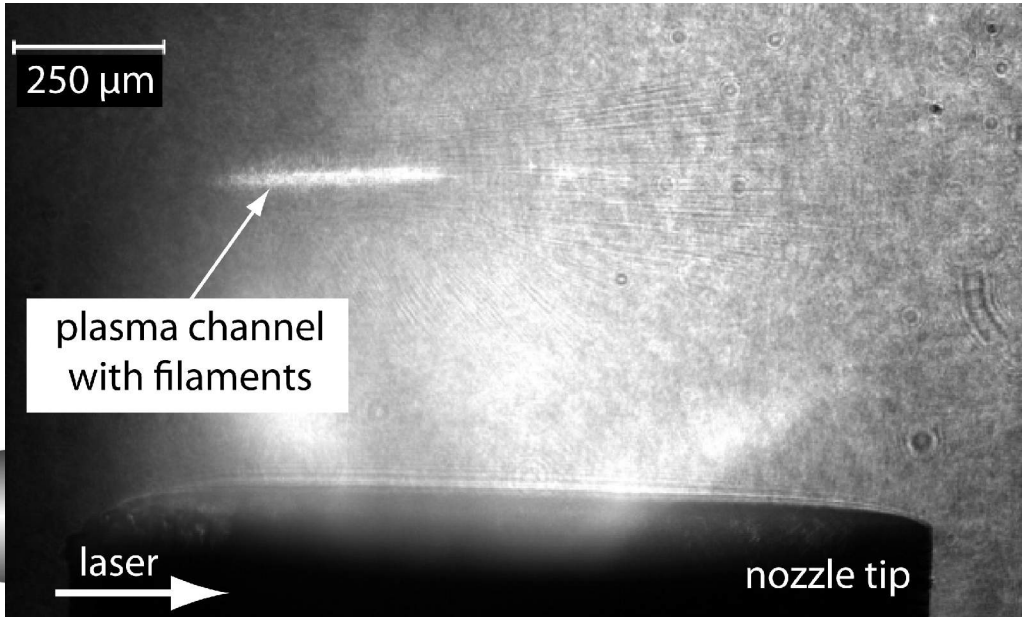
charged
particles

electrons
energy up to
several 100's of MeV

ions
energy up to
several 10's of MeV

Laser-target interaction





- supersonic gas jet
  - → $10^{19\text{-}20}$ cm^{-3}
- relativistic self-focusing:
  - → laser stays focused
- plasma channel evolves

Laser-target interaction

electrons

- laser pulse: Gaussian-distributed *E*-field (not a plane wave!)
  - intensity gradient
  - ponderomotive force

$$\boldsymbol{F}_{\mathrm{pon}} \propto -\nabla I_{\mathrm{L}}$$

- electrons affected by $\boldsymbol{F}_{\mathrm{pon}}$
  - quiver motion
  - e^- oscillate, pushed out, follow laser pulse

$$\boldsymbol{v}_{\mathrm{q}} \perp \boldsymbol{k}_{\mathrm{L}}, \ \beta = \frac{\boldsymbol{v}_{\mathrm{q}}}{c}$$

Laser-target interaction

ions

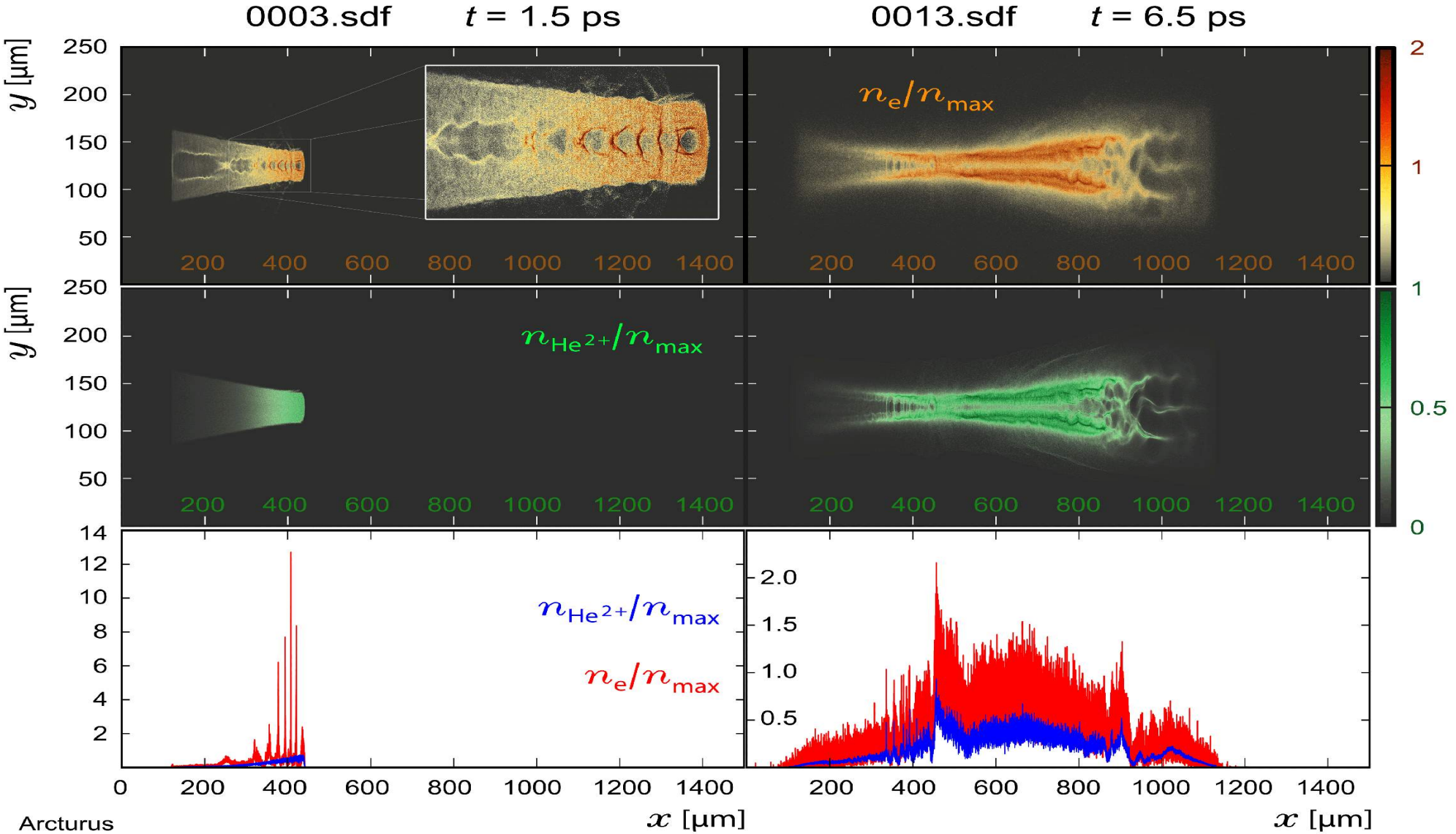
$$\frac{v_\mathrm{i}}{c} = \frac{e\ E_\mathrm{L}}{m_i\ \omega_\mathrm{L}\ c} = \frac{m_\mathrm{i}}{m_\mathrm{e}}\ a_0 \leq \frac{a_0}{1836 \times A}$$

$$a_0 \propto \sqrt{\lambda_\mathrm{L}^2\ I_\mathrm{L}}$$

- direct laser-driven **ion** acceleration?
  - ➔ requirement: intensity-wavelength products $\sim \lambda^2\ I_L \geq 10^{24}\ \mathrm{W}\ \frac{\mu\mathrm{m}^2}{\mathrm{cm}^2}$

    or: $a_0 \sim 2000$
  - ➔ nowadays not reachable
- ion acceleration indirectly: **charge separation**: *E*-fields $O(10^{10\text{-}12}$ V/m)

Laser-target interaction

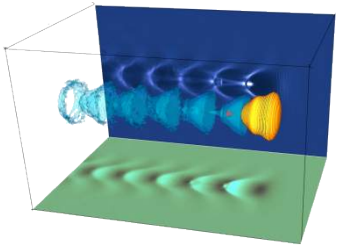


Laser-driven ion acceleration: ion-beam polarization?

- laser and plasma: magnetic fields (~ $10^{3\text{-}4}$ T)
- 2 scenarios possible:
  - a) polarization **creation**: *cf.* N. Raab et al., Phys. Plasmas 21, 023104 (2014)
    - → spin flip, Stern-Gerlach?
    - → *no* polarization observed for laser-acc. proton beams
  - a) polarization **conservation**
    - → pre-polarized target: ^{3}He gas (AG Heil, Mainz) @3 bar, 293 K
    - → full ionization within 0.x ps < hyperfine interaction time 0.2 ns
    - → laser/plasma fields vanish too quickly

Outline

- Lasers as compact accelerators



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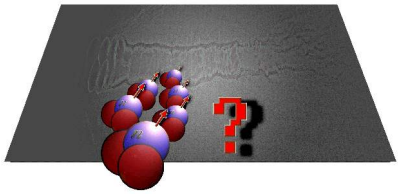
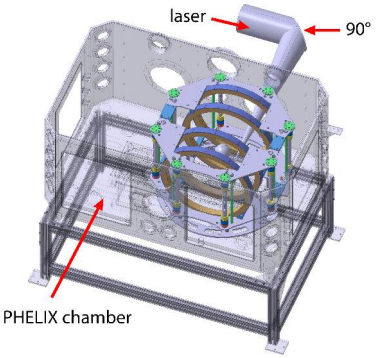
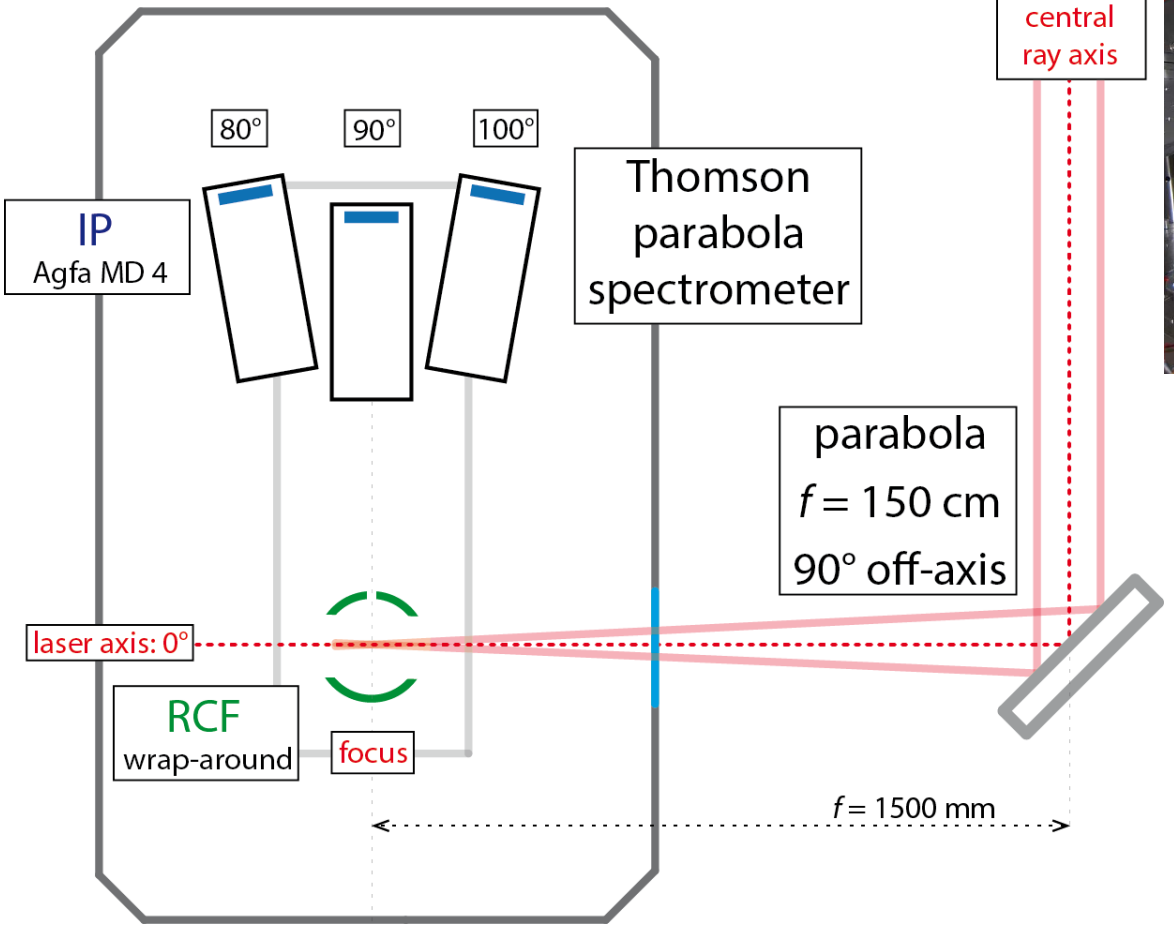
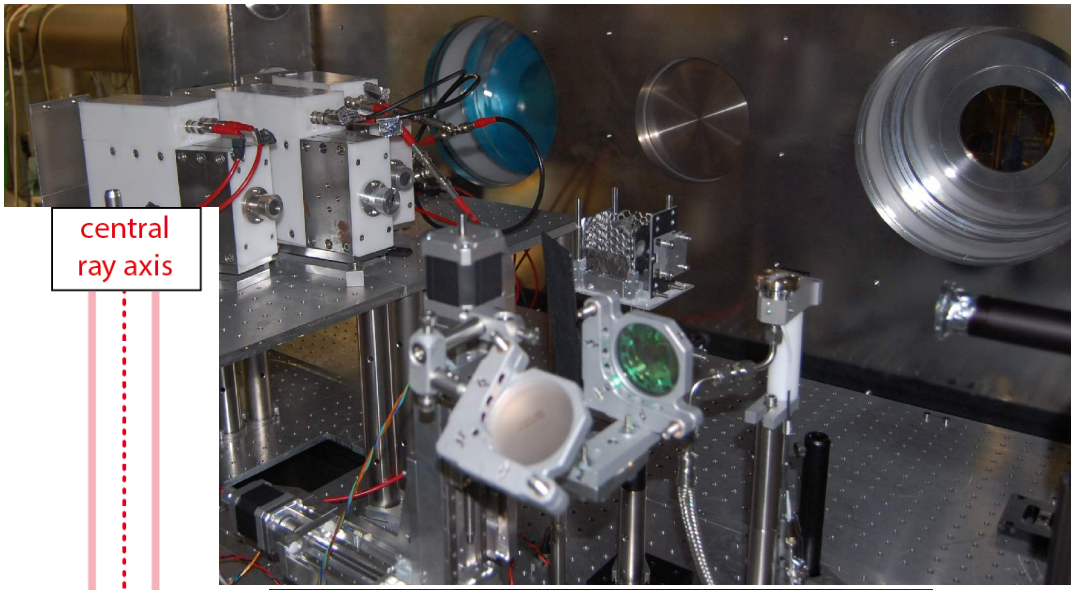


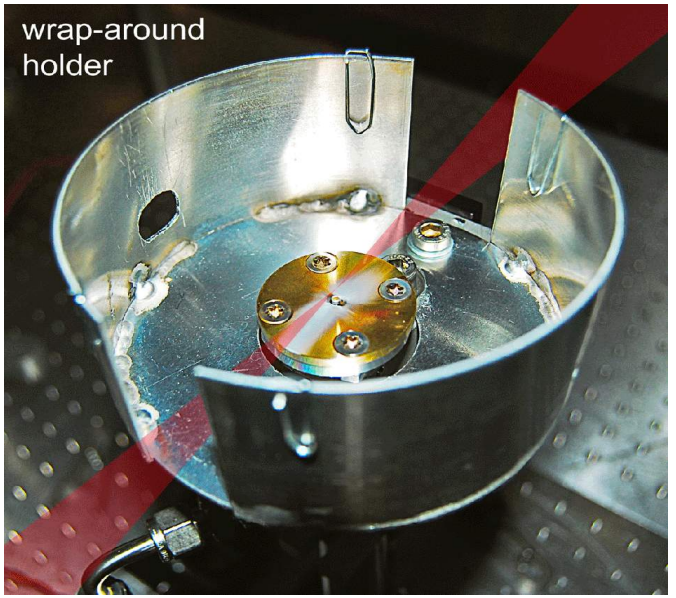
- Polarized ^{3}He target



PHELIX experiment: setup





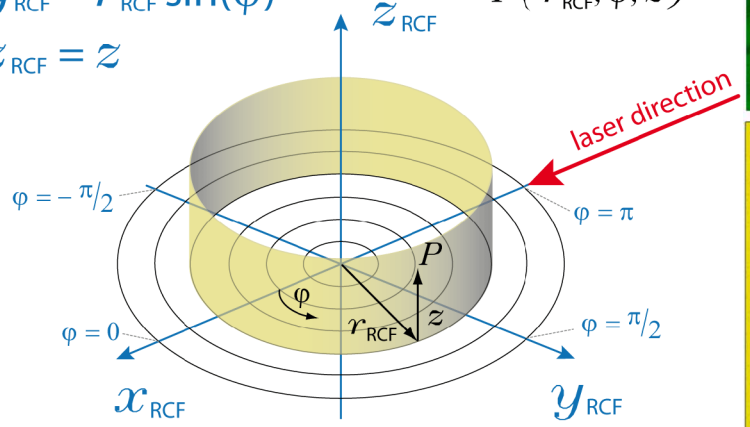


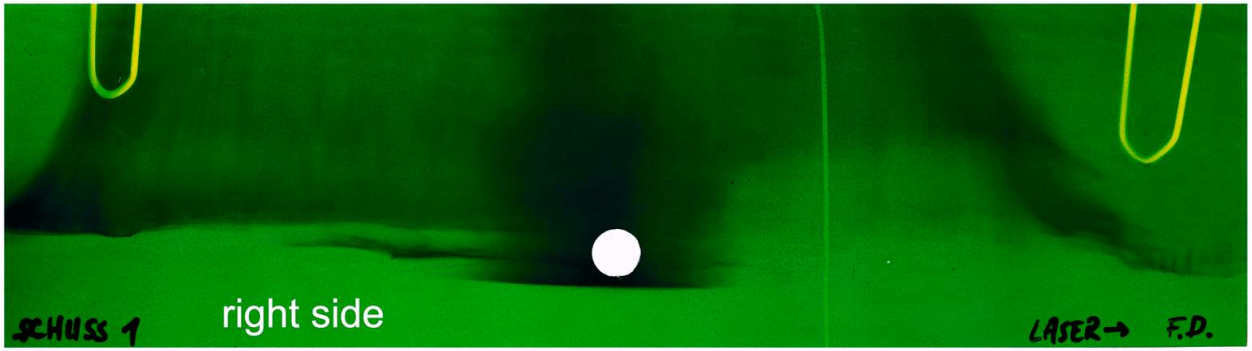
$^{4}He^{1+,2+}$ angular distribution

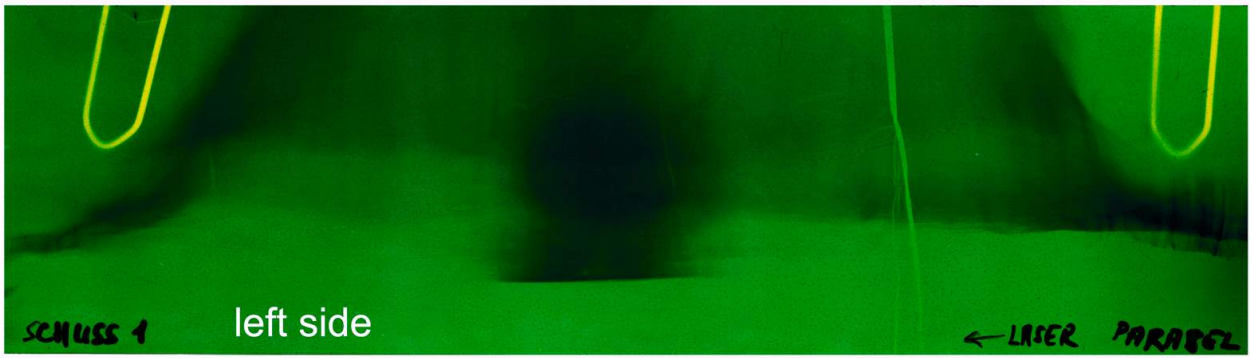
- radiochromic films
  - → 5 µm Al shielding
  - → He ions > 1.6 MeV

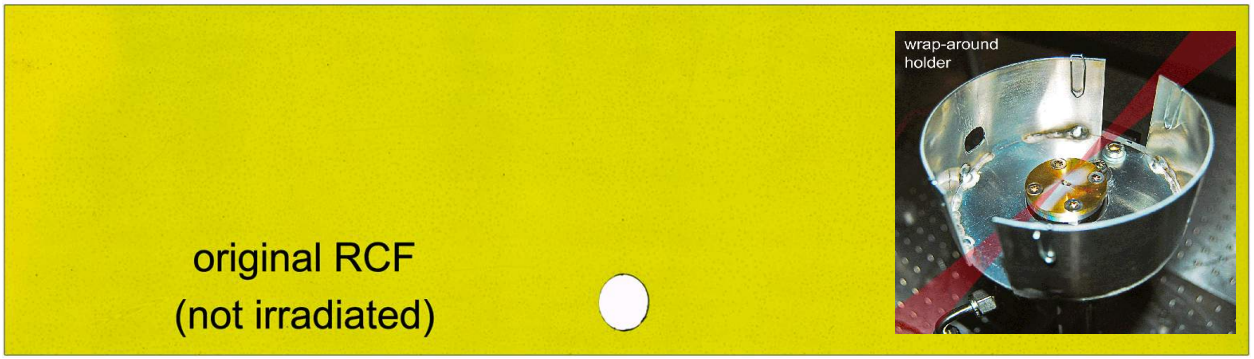
$$x_{RCF} = r_{RCF}\cos(\varphi)$$
$$y_{RCF} = r_{RCF}\sin(\varphi)$$
$$z_{RCF} = z$$

$P(r_{RCF}, \varphi, z)$









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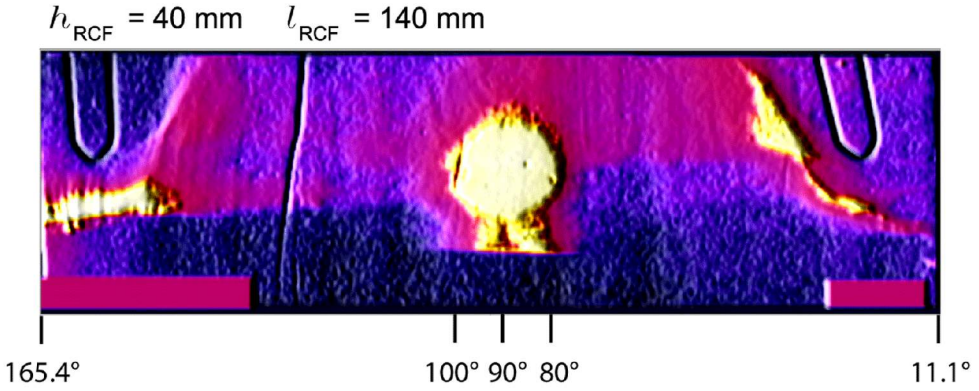
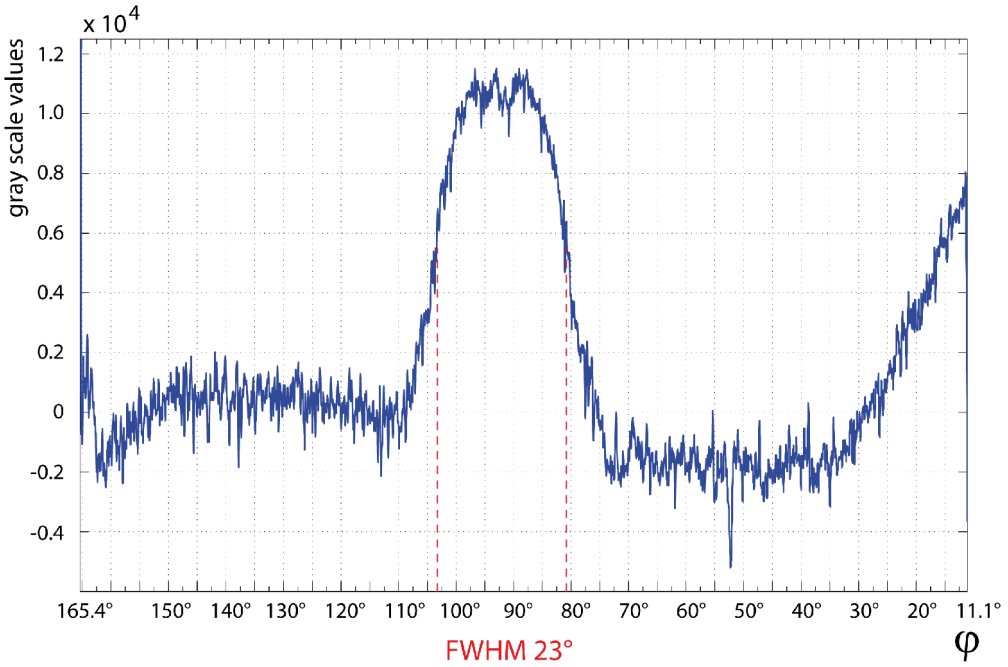
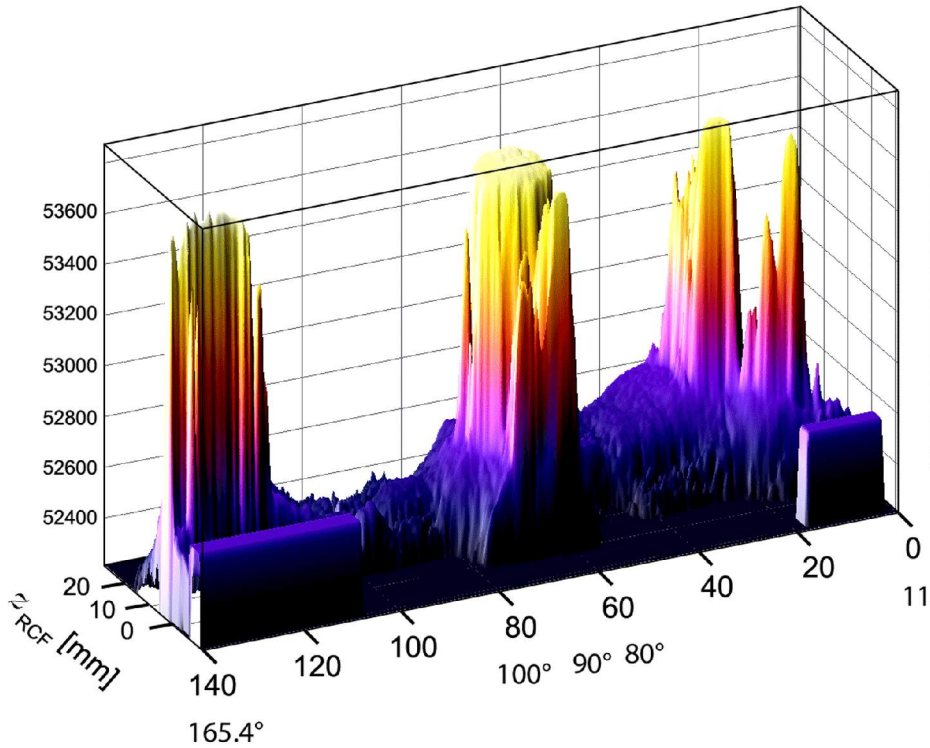
$^4He^{1+,2+}$ angular distribution







11.1°:	b_{RCF} = 0 mm
80°:	b_{RCF} = 62.53 mm
90°:	b_{RCF} = 71.61 mm
100°:	b_{RCF} = 80.68 mm
165.4°:	b_{RCF} = 140 mm

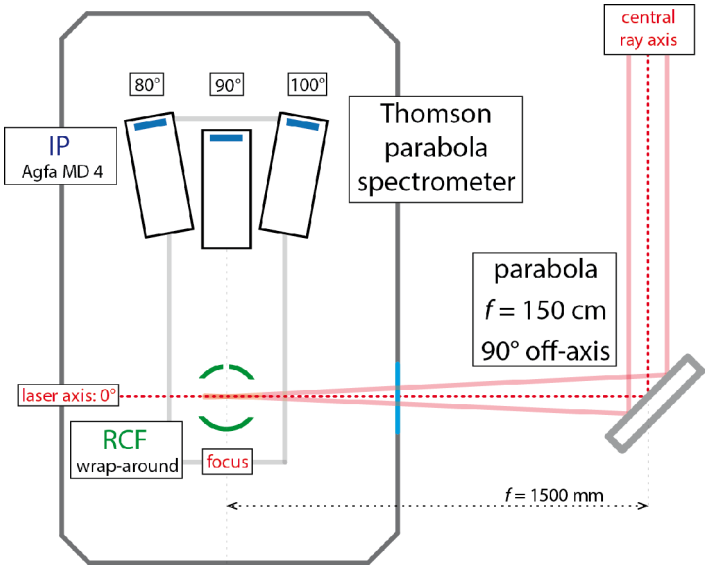
- FWHM: 80.7° - 103.7°

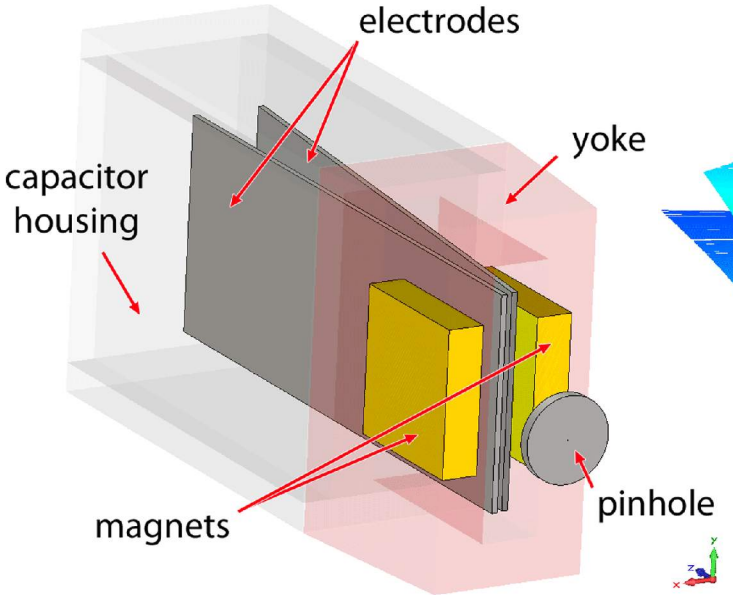
➔ TPs @ 80°, 90°, 100°

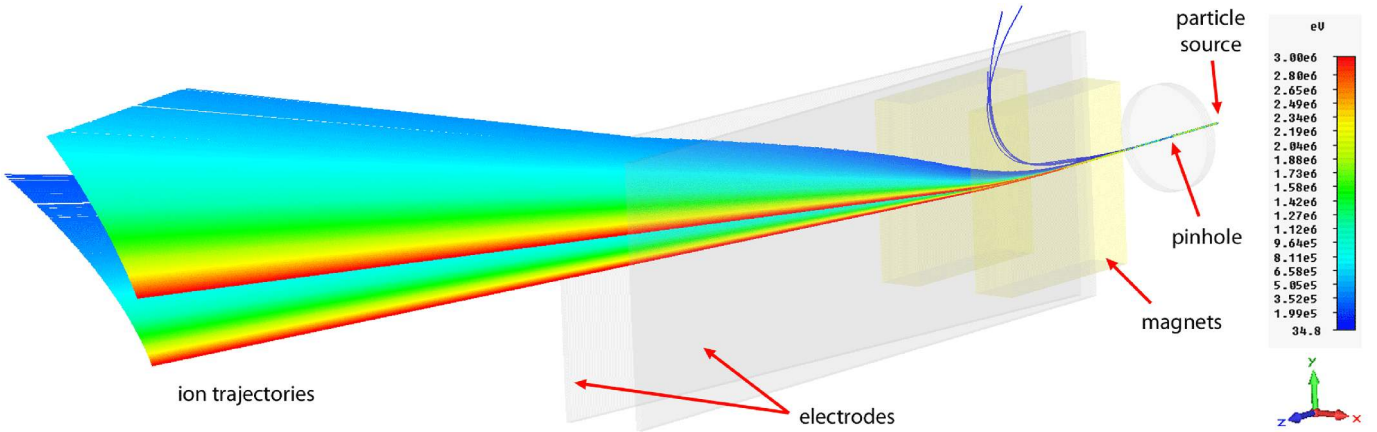
TP measurements: energy spectra

Thomson parabola spectrometer (TP)

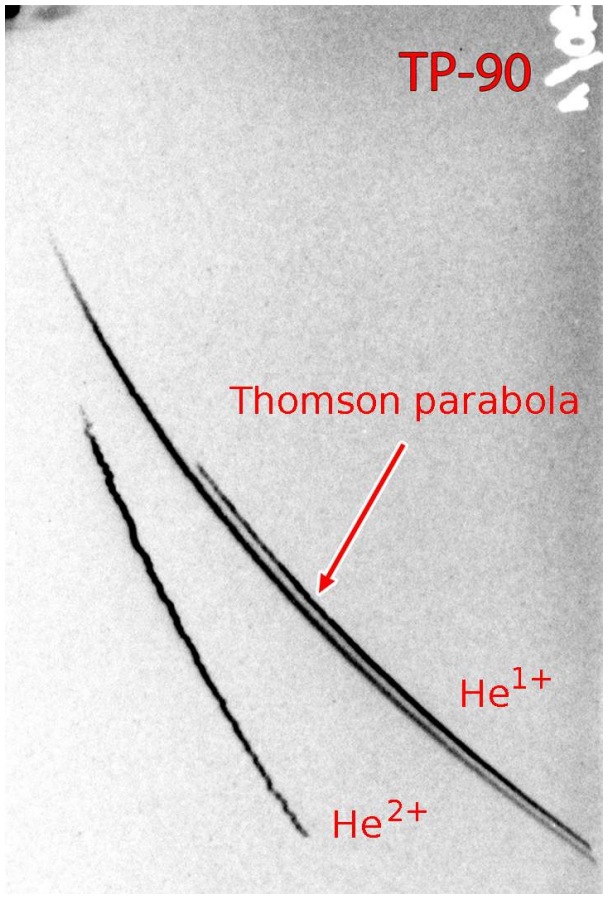
- HV 3 kV, 0.58 T, 200 µm pinhole, 170 nSr
- TPs @ 80°, 90°, 100°
- ion detector: image plates (IP)

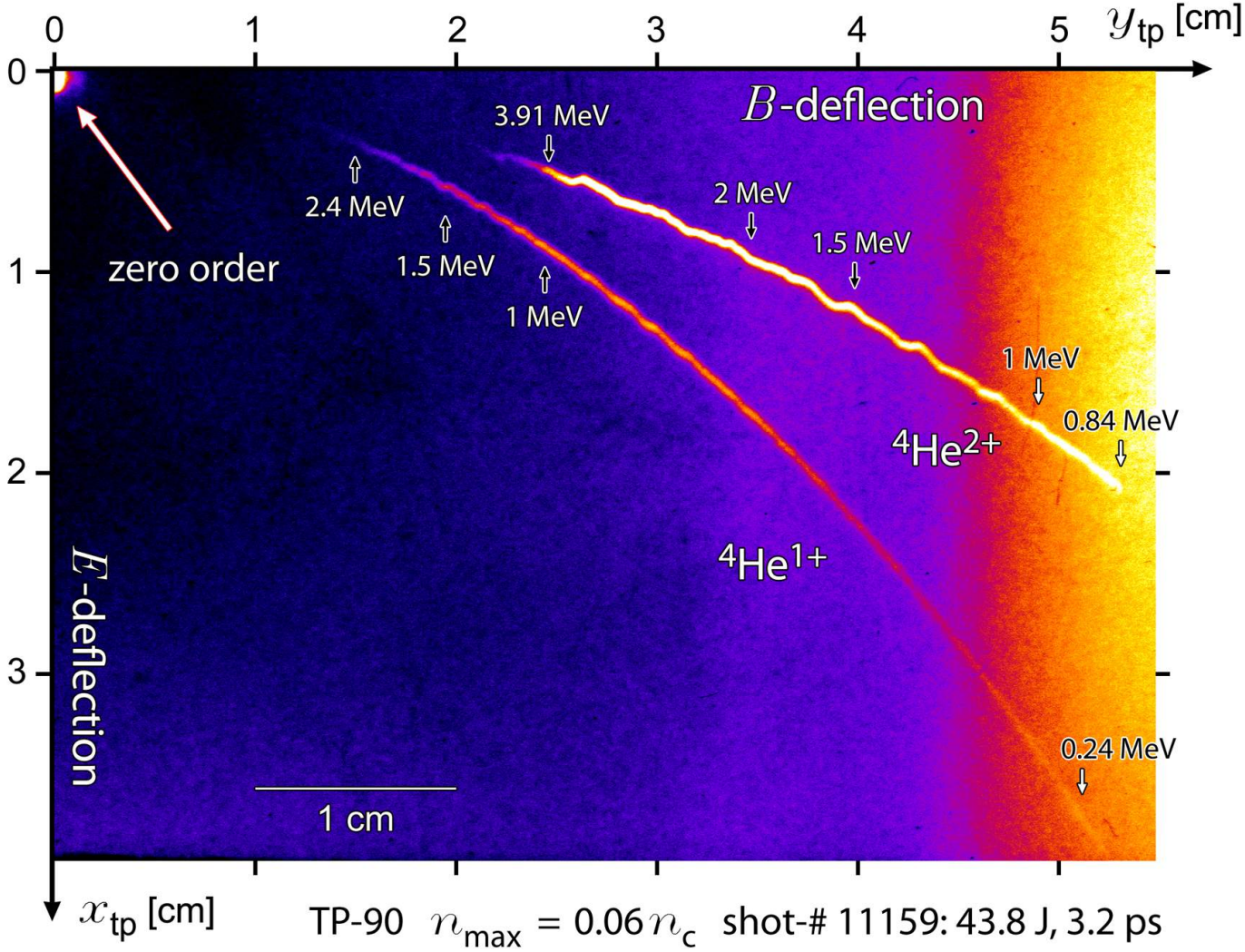






TP measurements: energy spectra





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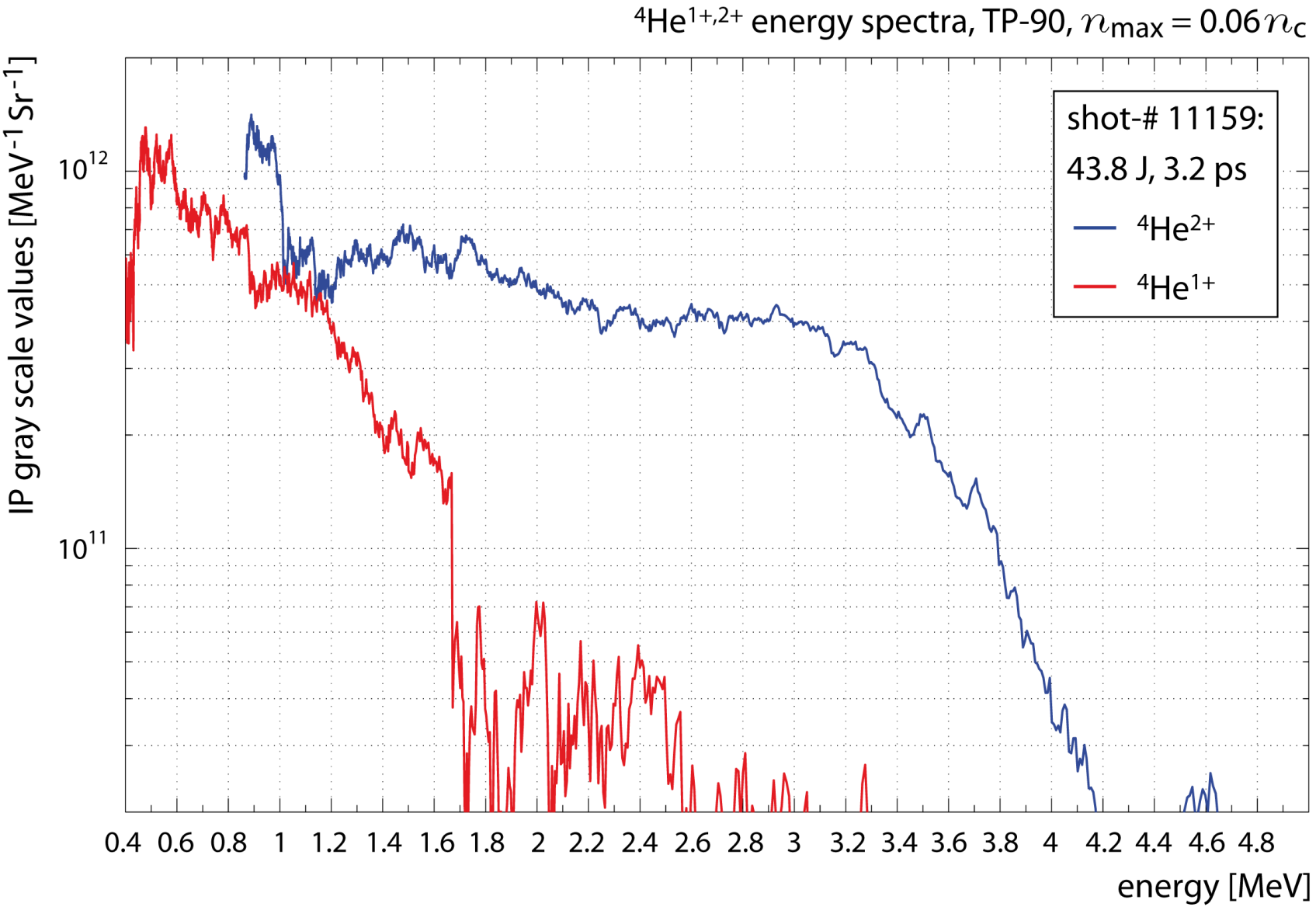

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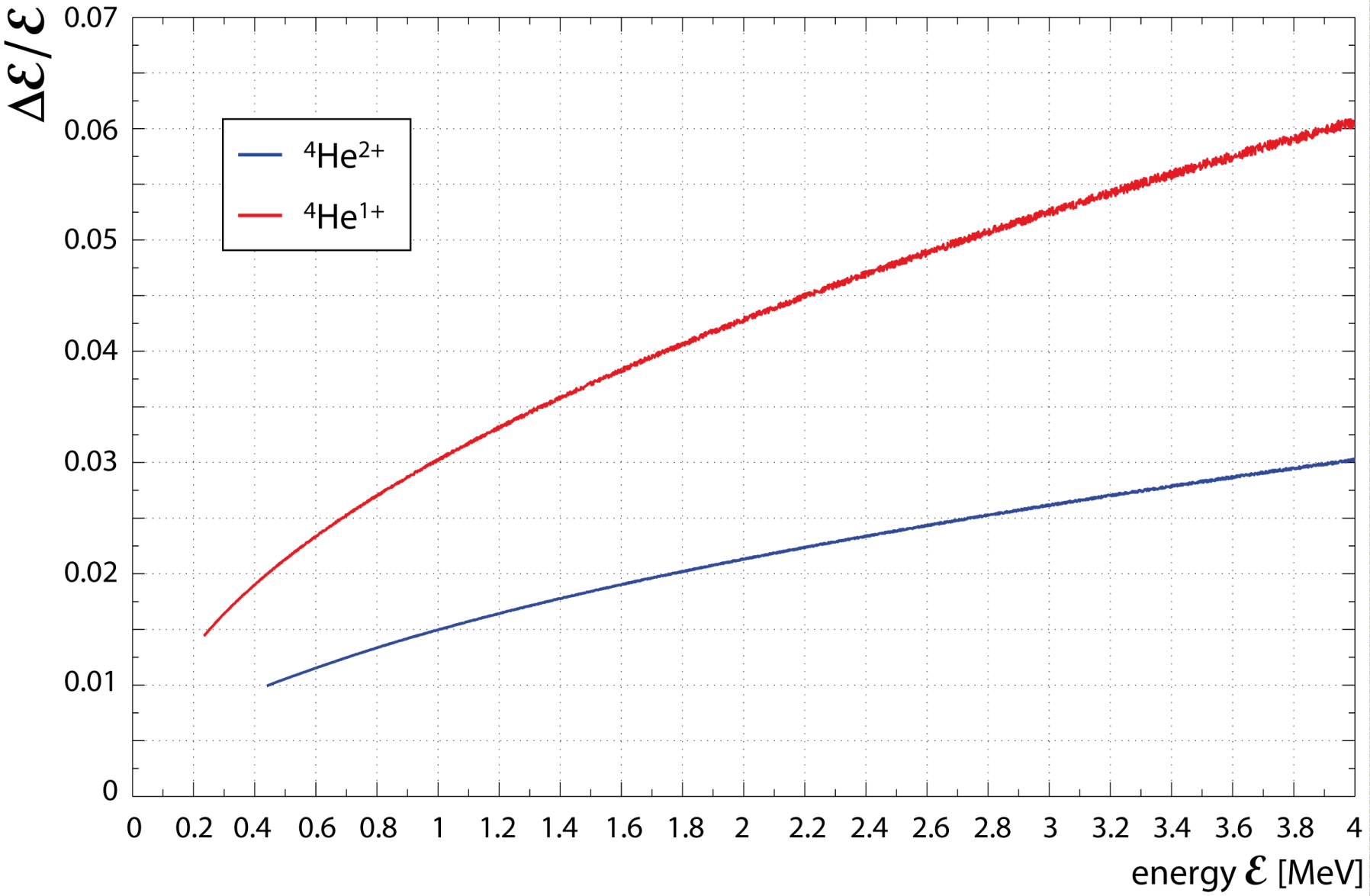

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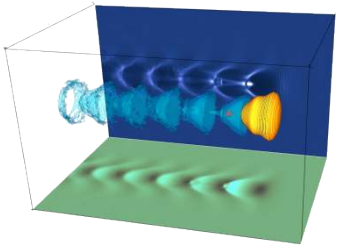

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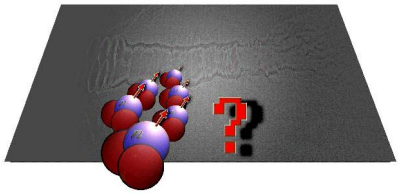
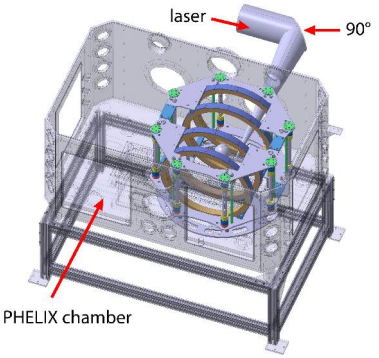


- Polarized ^{3}He target



Layout: polarized ^{3}He laser target

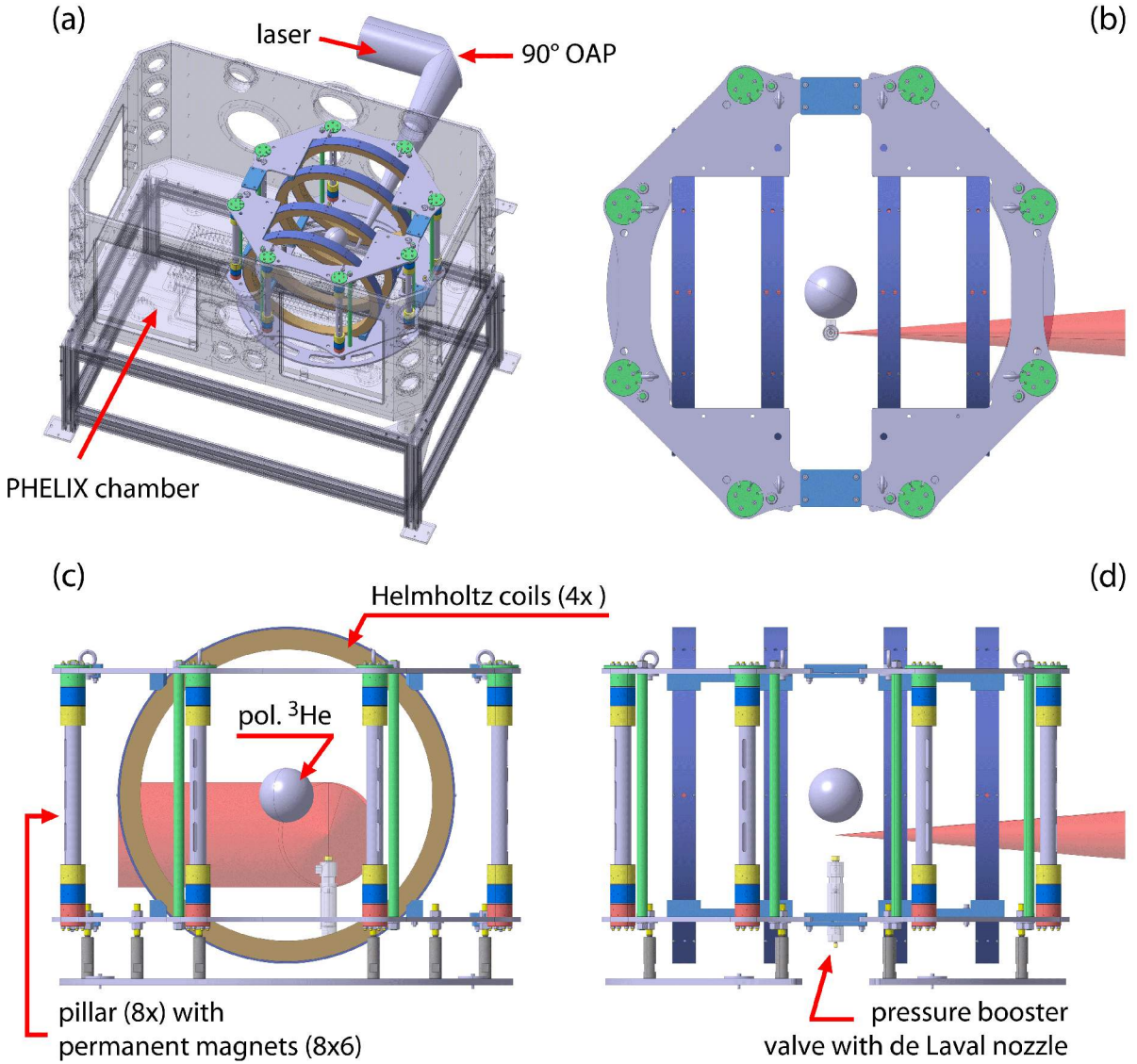
homogeneous magnetic holding field: 1 mT

Halbach array

2 Halbach rings,
48 permanent magnets

Helmholtz-coil configuration

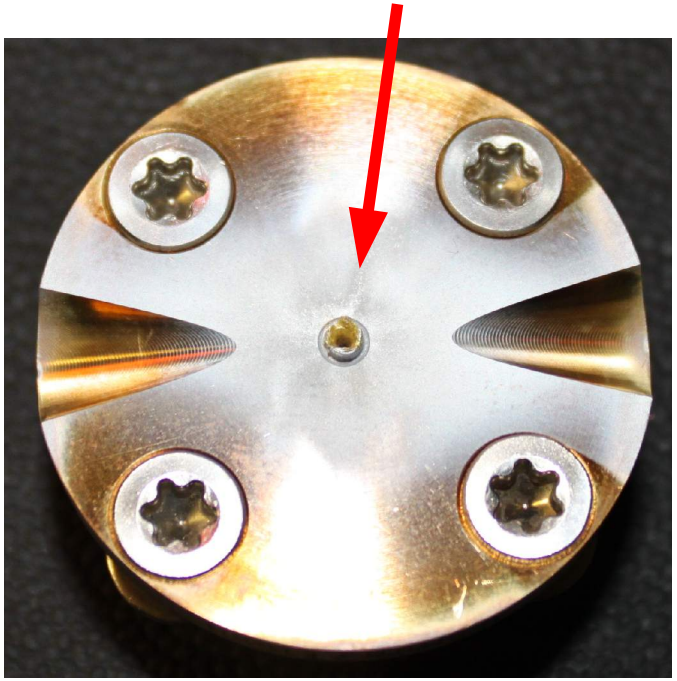
4 coils

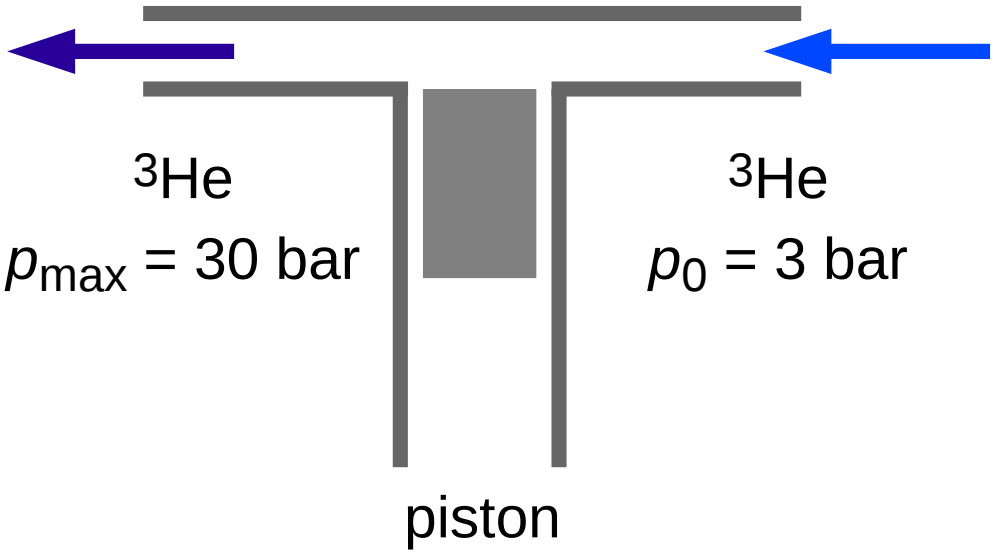


Layout: polarized ^{3}He laser target

pressure booster and piezo-/pressure-driven valve:

- non-magnetic materials and operation mechanism
- tenfold increase of the ^{3}He backing pressure *i.e.* the particle density
- appropriate for laser-acceleration experiments with high-energy lasers
  - ➔ (*cf.* brass nozzle and solenoid valve during shots)





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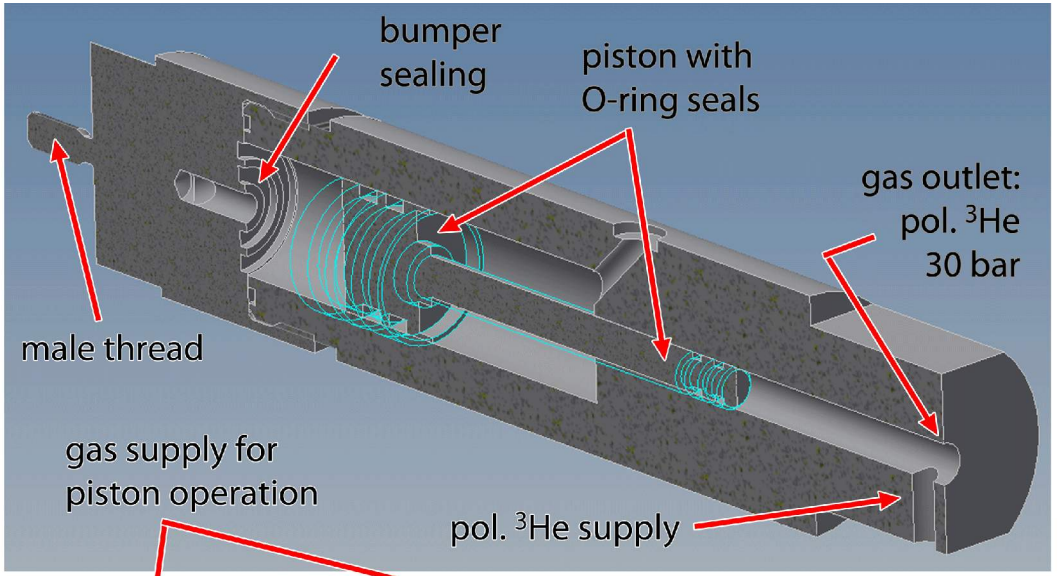
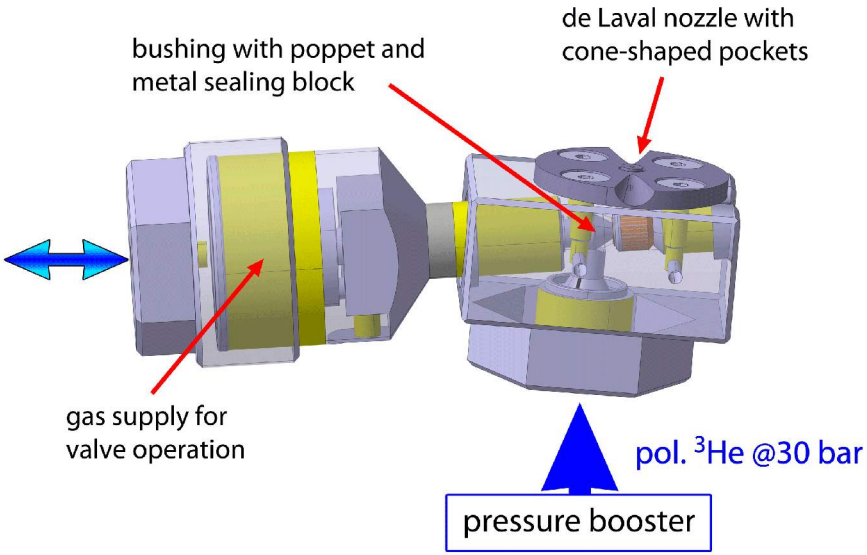
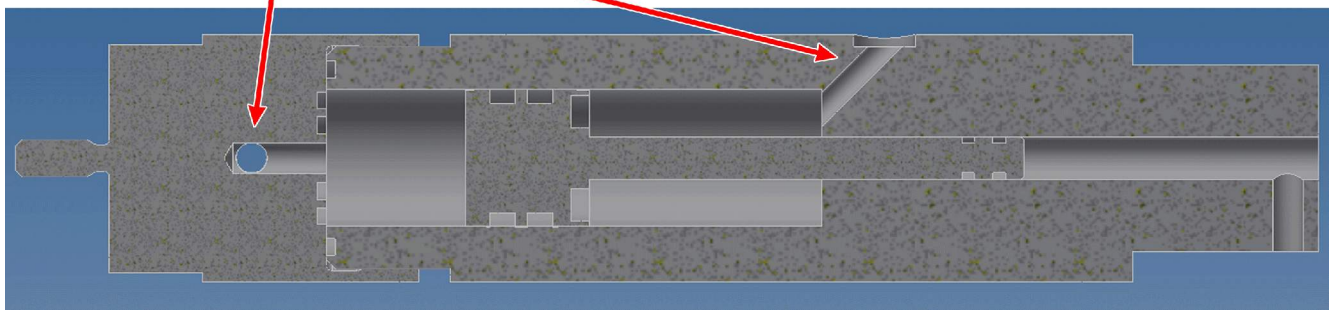
Layout: polarized ^{3}He laser target

pressure booster and piezo-/pressure-driven valve







Layout: polarized ^{3}He laser target

polarimetry

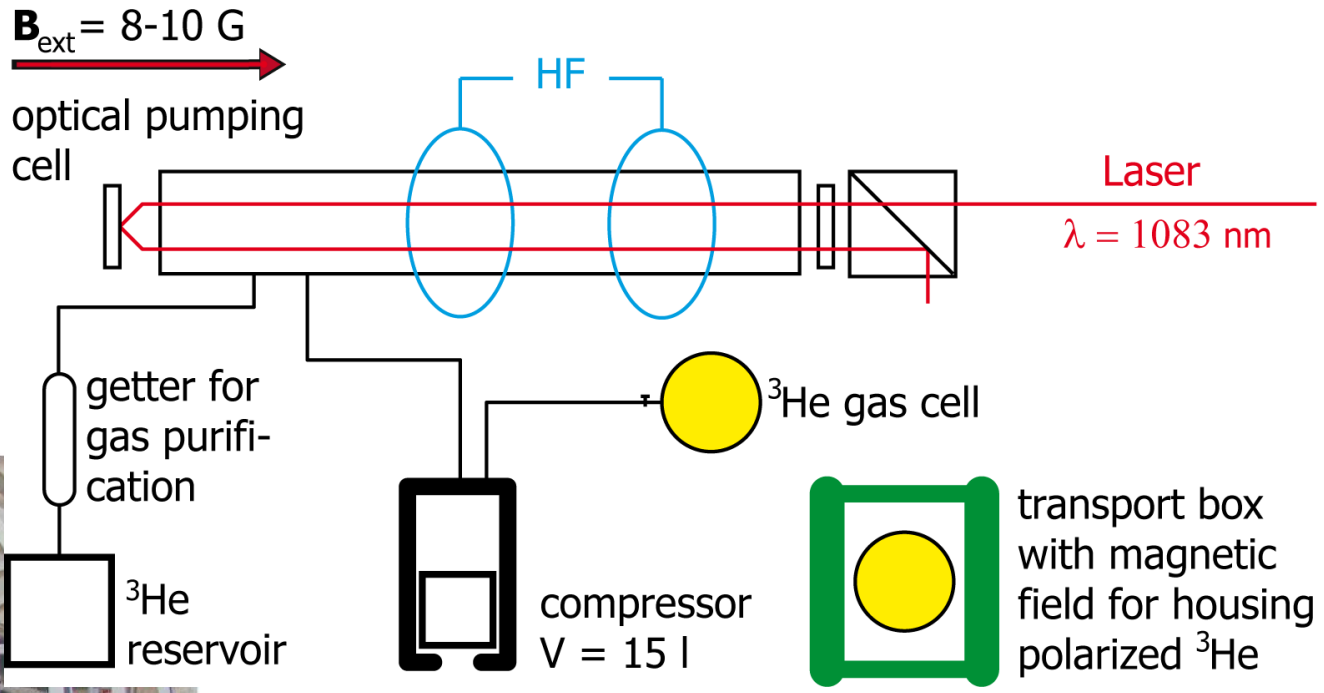
- extraction of laser-accelerated $^3He^{2+}$ ion beam
- acceleration angle: +/- 90°
- proper nuclear analytical reaction

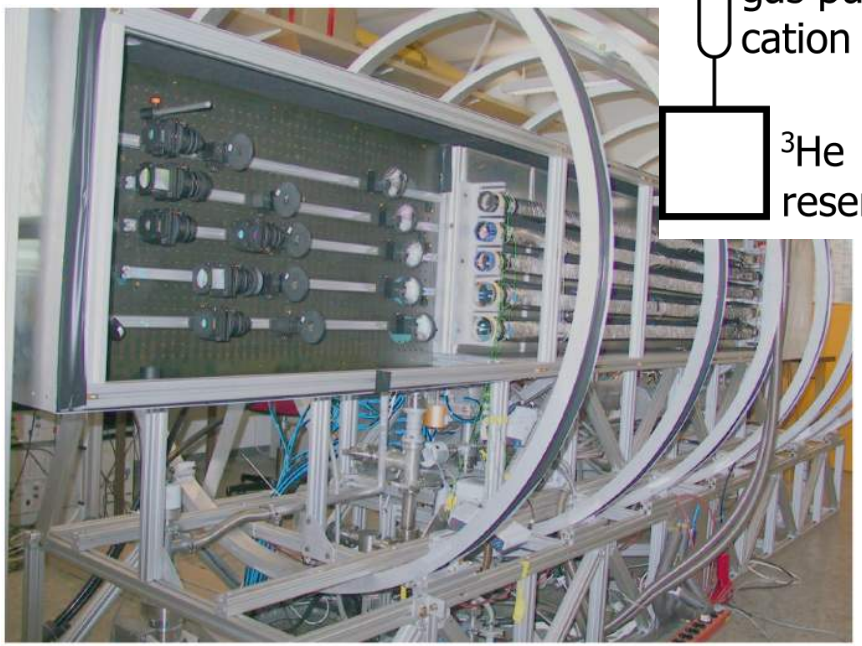
  with known x-sections & analyzing powers?

  ➔ $^3He^{2+}$ polarization measurement

Thank you...

Mainz ^{3}He polarizer





Metastable **E**xchange **O**ptical **P**umping

polarization degree: up to 85%

W. Heil

http://www.ag-heil.physik.uni-mainz.de/32_ENG_HTML.php